Impact of Convectively Detrained Ice on the Tropical UTLS H_2O

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Two-step Convective Processes

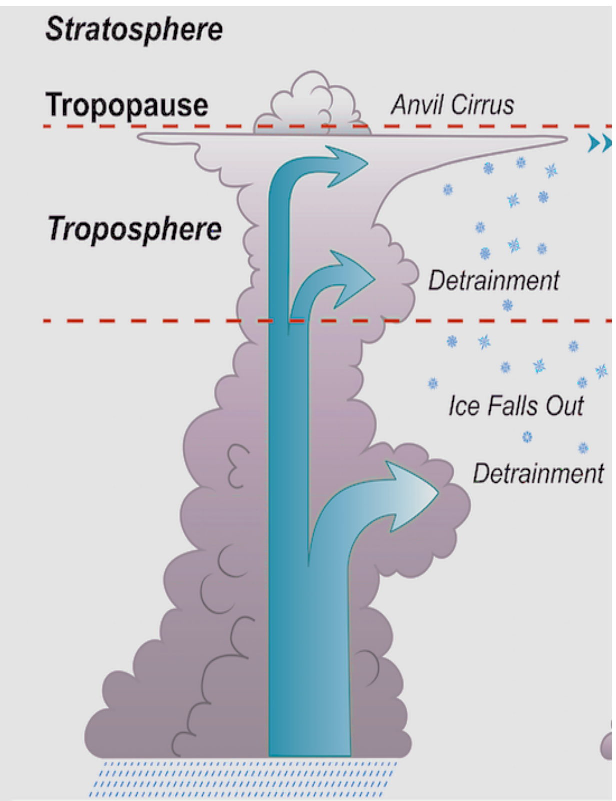


illustration by Barbara Schoeberl

Deep convection modifies UTLS humidity by

(1) saturating the air within the convective plume instantly
(2) detraining ice crystals that can either hydrate or dehydrate the UTLS some distance away from the convective plume with some time lag (i.e., ice crystal lifetime)

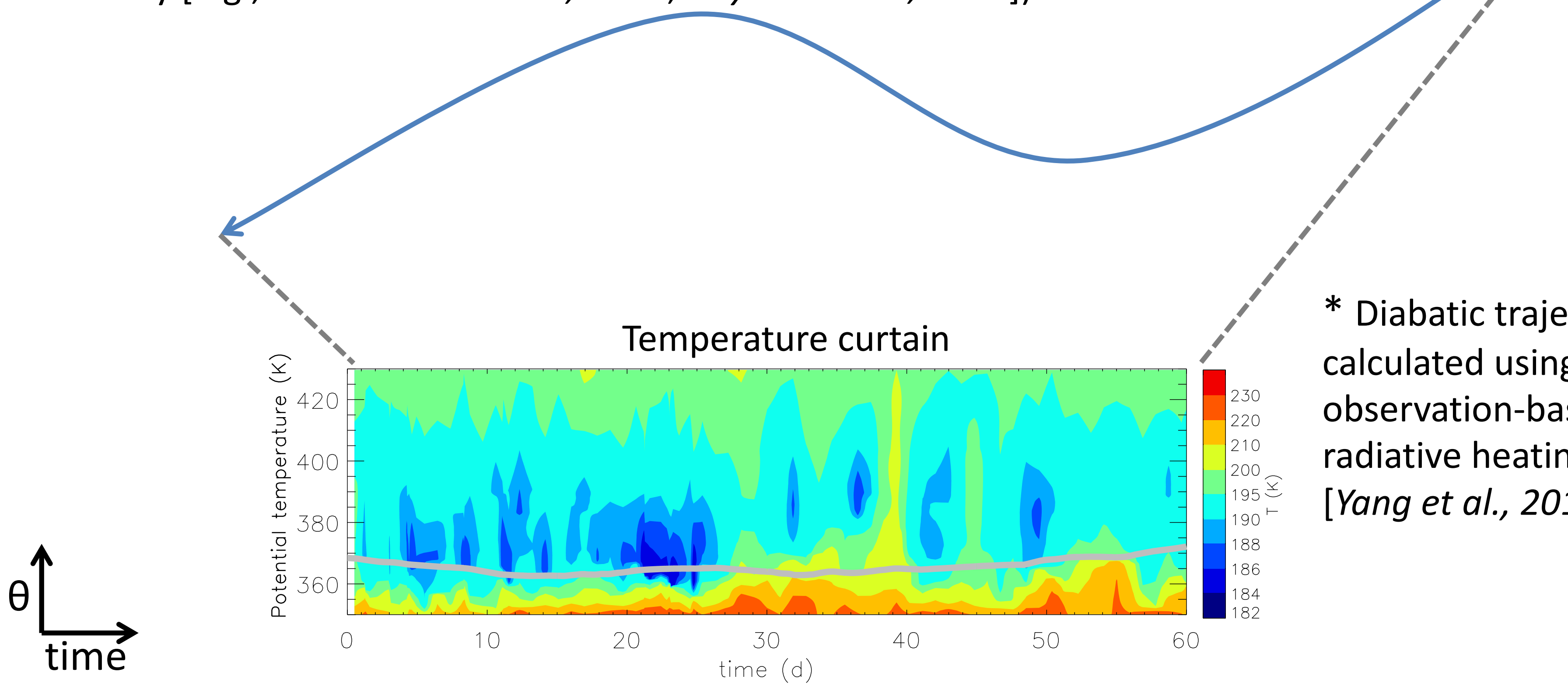
- Ice crystals detrained in a warming environment will sublimate and **hydrate**.
- Ice crystals detrained in a cooling environment will quench vapor in excess of saturation, fall out, and **dehydrate.**

[e.g., *Jensen et al., 2007*; *Schoeberl et al., 2018*]

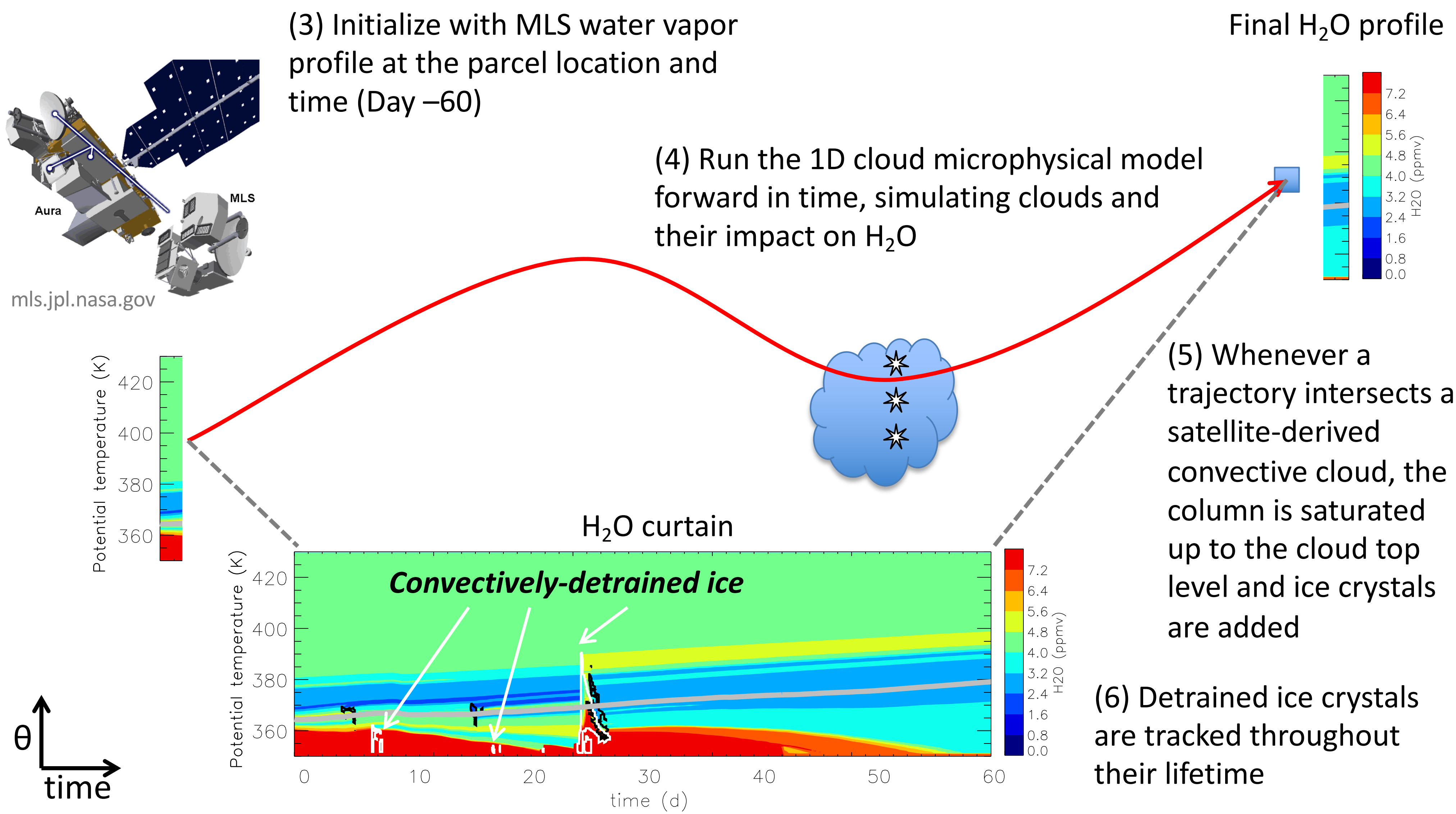
Methodology

(1) Calculate a 60-d backward diabatic* trajectory from 2° lon x 2° lat grid point in the tropics at the 378K level on 1 Feb 2007

(2) Extract temperature profiles along the trajectory path from ERA-Interim reanalysis (with wave-enhanced temperature variability [e.g., *Kim and Alexander, 2013*; *Ueyama et al., 2018*])



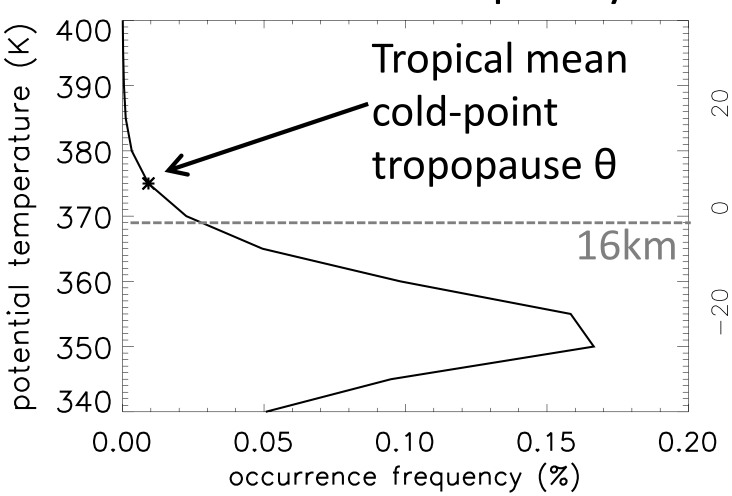
* Diabatic trajectories are calculated using observation-based radiative heating rates [*Yang et al., 2010*]



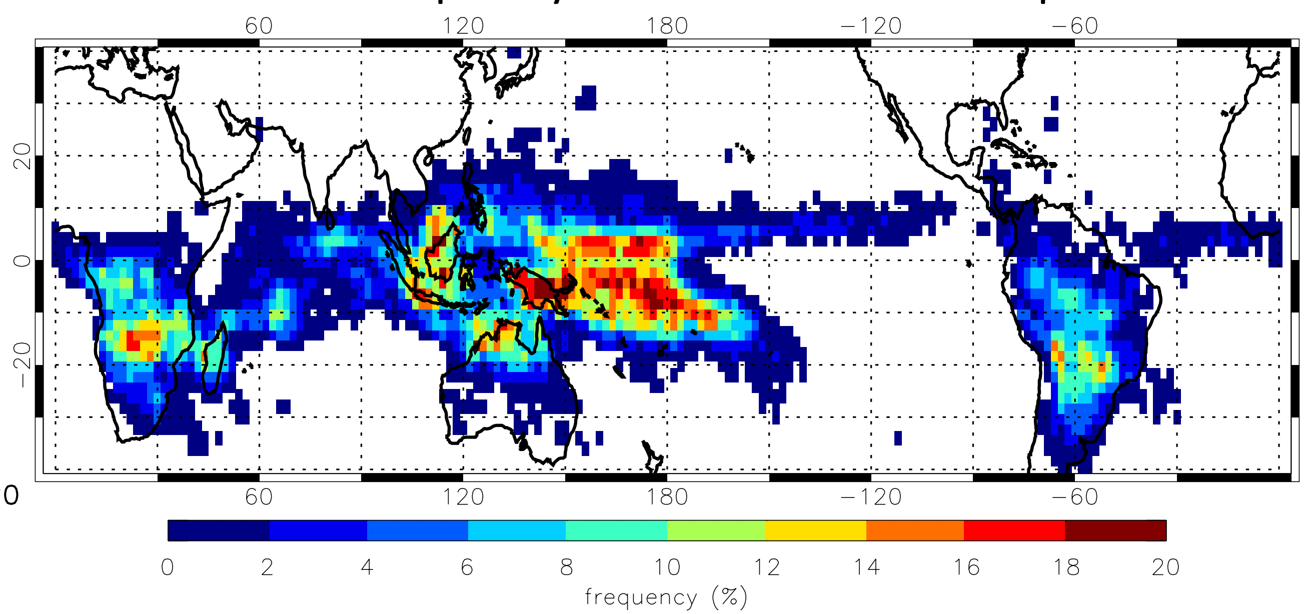
(3) Initialize with MLS water vapor profile at the parcel location and time (Day –60)
Aura
MLS
mls.jpl.nasa.gov
Final H_2O profile
(4) Run the 1D cloud microphysical model forward in time, simulating clouds and their impact on H_2O
(5) Whenever a trajectory intersects a satellite-derived convective cloud, the column is saturated up to the cloud top level and ice crystals are added
(6) Detrained ice crystals are tracked throughout their lifetime
H_2O curtain
Convectively-detrained ice
Potential temperature (K)
time (d)
H2O (ppmv)
θ
time

Convective cloud top distribution during boreal winter 2006-07

Tropical (20S-20N) mean occurrence frequency

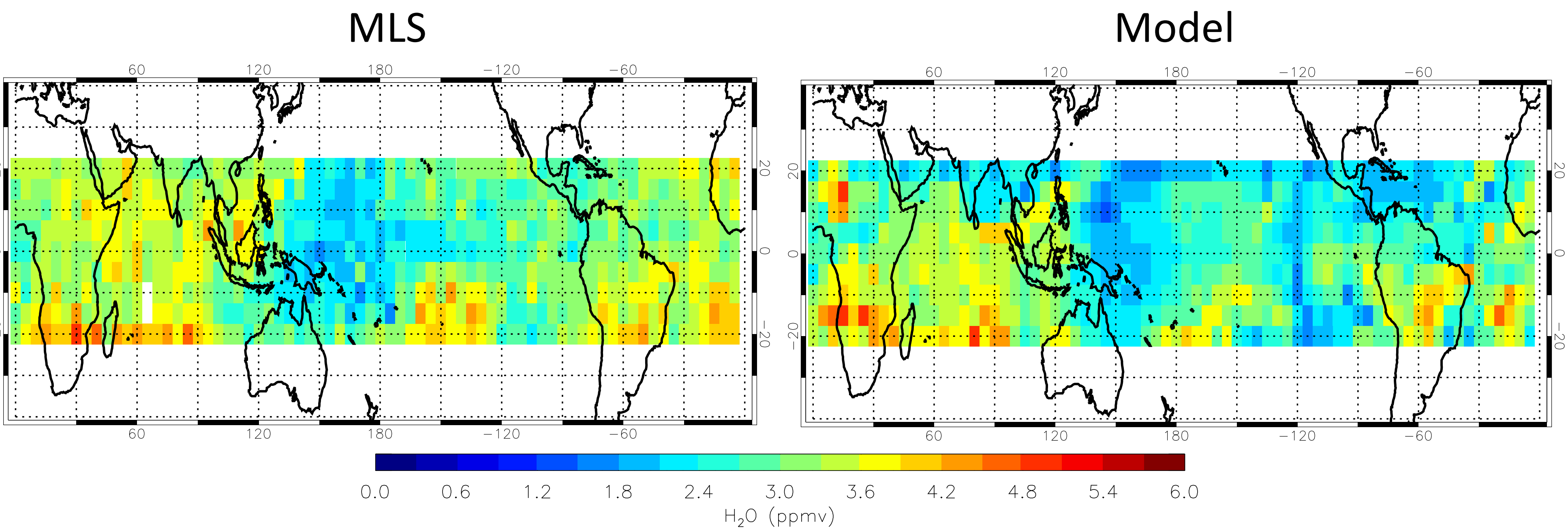


Occurrence frequency of convective cloud top ≥16km



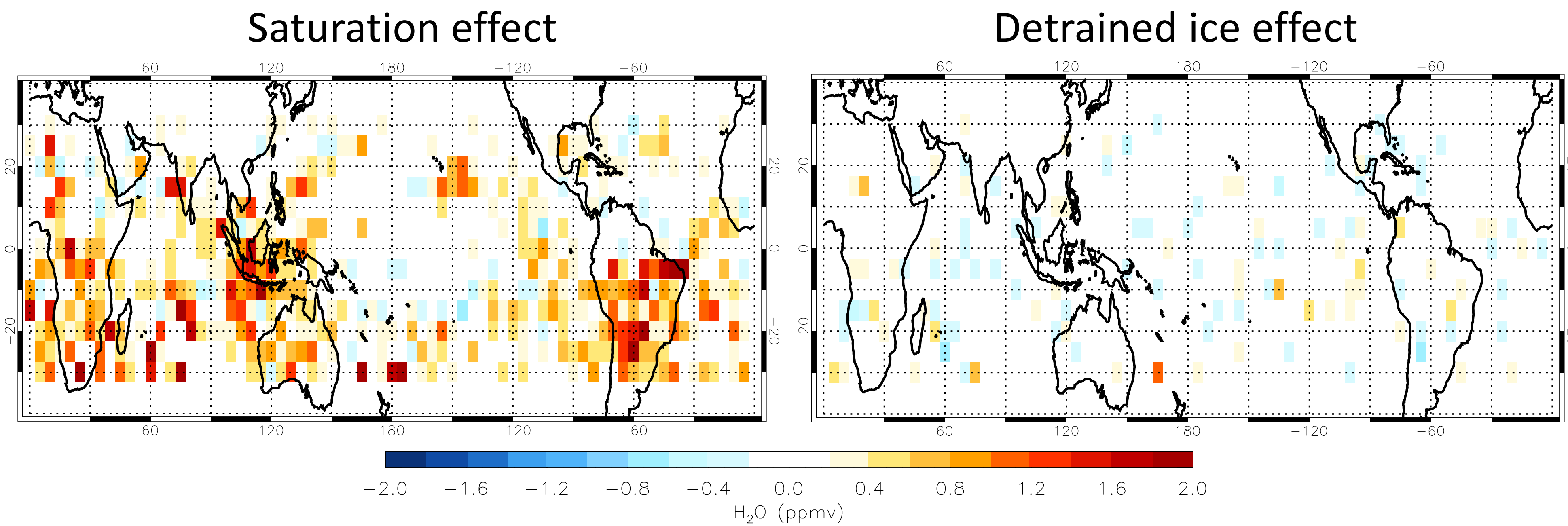
Convective cloud top altitudes are calculated using geostationary IR satellite imagery (along with TRMM/GPM precip), and calibrated to statistically match CloudSat and CALIOP observations.

H_2O at 100 hPa on 1 Feb 2007



Simulated H_2O field agrees reasonably well with MLS observations.

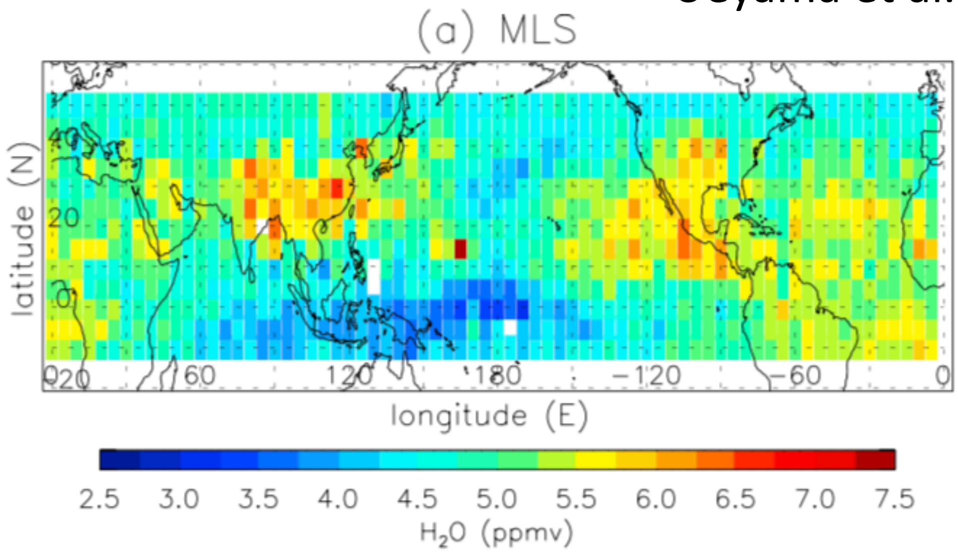
Impact of convection on 100-hPa H_2O

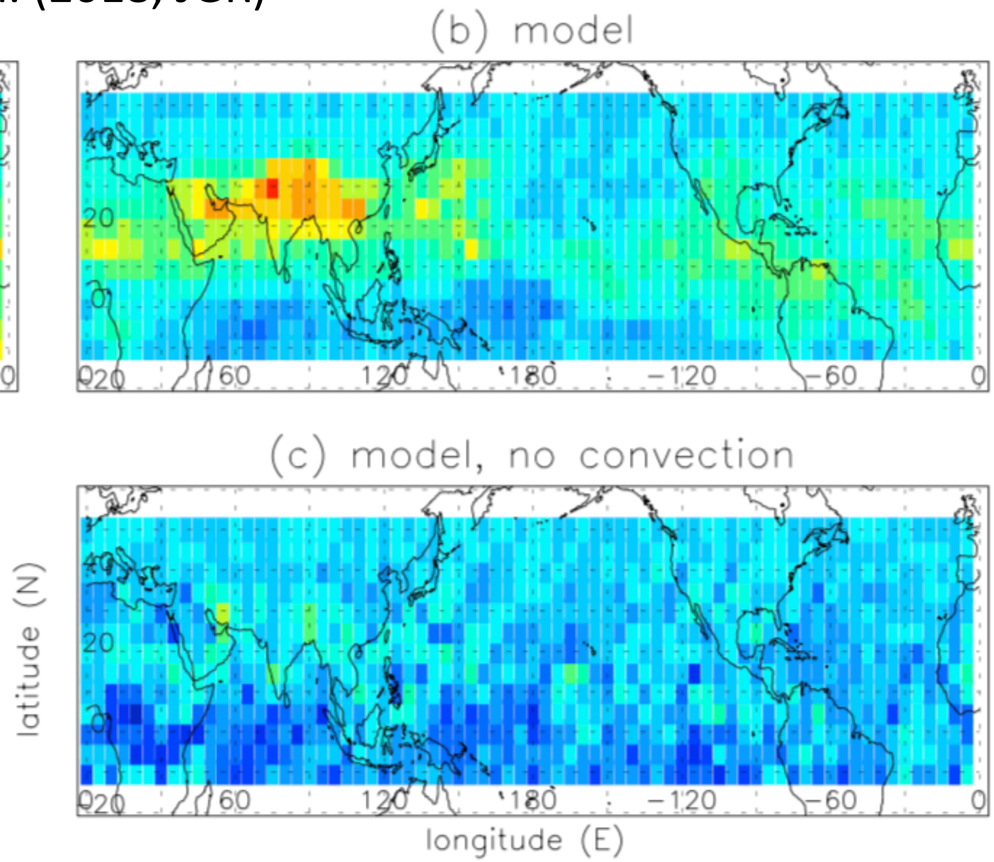


In the tropical mean, the saturation effect of convection increases 100-hPa H_2O by 0.25 ppmv while detrained ice crystals have negligible impact (dehydration of 0.01 ppmv).

Summertime impact is much larger

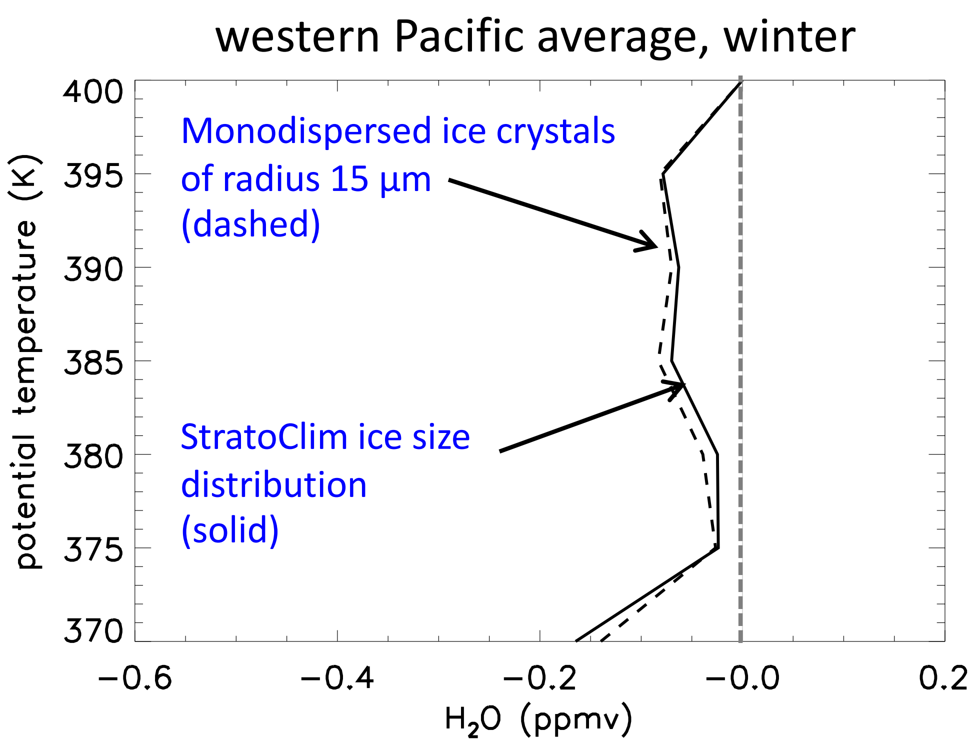
Ueyama et al. (2018, JGR)





- During Boreal summertime, convective saturation increases 100-hPa H_2O by 0.5–1 ppmv
- Convection is responsible for the monsoon maxima
- Detrained ice contribution is still very small

Mean impact of a detrained ice crystal



Calculate the impact of a single detrained ice crystal on TTL H_2O (from start to end of its lifetime), then average the impact over all detrained ice crystals in the western Pacific:

- Ice crystals detrained from convection over the western Pacific predominantly <u>dehydrate</u> the TTL, but <u>the effect is small</u> (<0.1 ppmv).
- Preliminary results of a sensitivity test with StratoClim ice size distribution indicate <u>weak sensitivity to ice crystal size distribution and ice water content</u>.

Conclusions

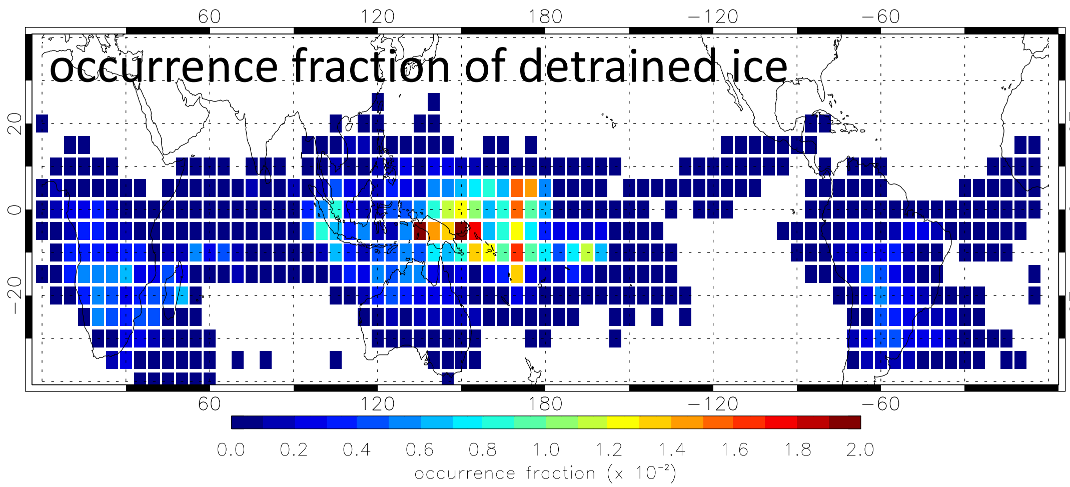
- Dehydrating effect of detrained ice over the western Pacific during boreal winter is small (~0.1 ppmv) and not very sensitive to ice crystal size distribution and ice water content.
- Moistening by convective saturation (0.25 ppmv) overwhelms the dehydration by detrained ice during boreal winter.
- During summertime, moistening effect is larger (0.5–1 ppmv) and mostly occurs over the monsoon regions.

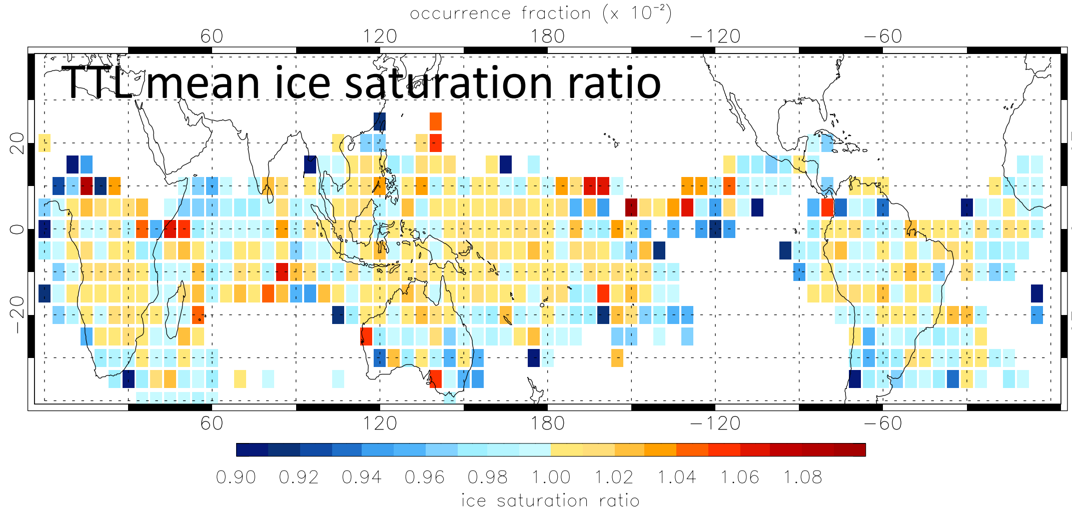
- Convective influence on stratospheric humidity is quite small (2%) during Boreal winter (Schoeberl et al., 2018, JGR). Boreal summertime calculations in progress….

Conclusions

- Air parcels in the tropics just above the cold-point tropopause during boreal winter are predominantly influenced by convection over the western Pacific.
- Ice crystals detrained from deep convection over the western Pacific often encounter super-saturated air due to slight cooling downstream.
- Ice crystals grow and sediment, leaving behind dry air.
- **Dehydrating effect of detrained ice over the western Pacific during boreal winter is small (~0.1 ppmv) and not very sensitive to ice crystal size distribution and ice water content.**
- Moistening by convective saturation (0.25 ppmv) overwhelms the dehydration by detrained ice during boreal winter.

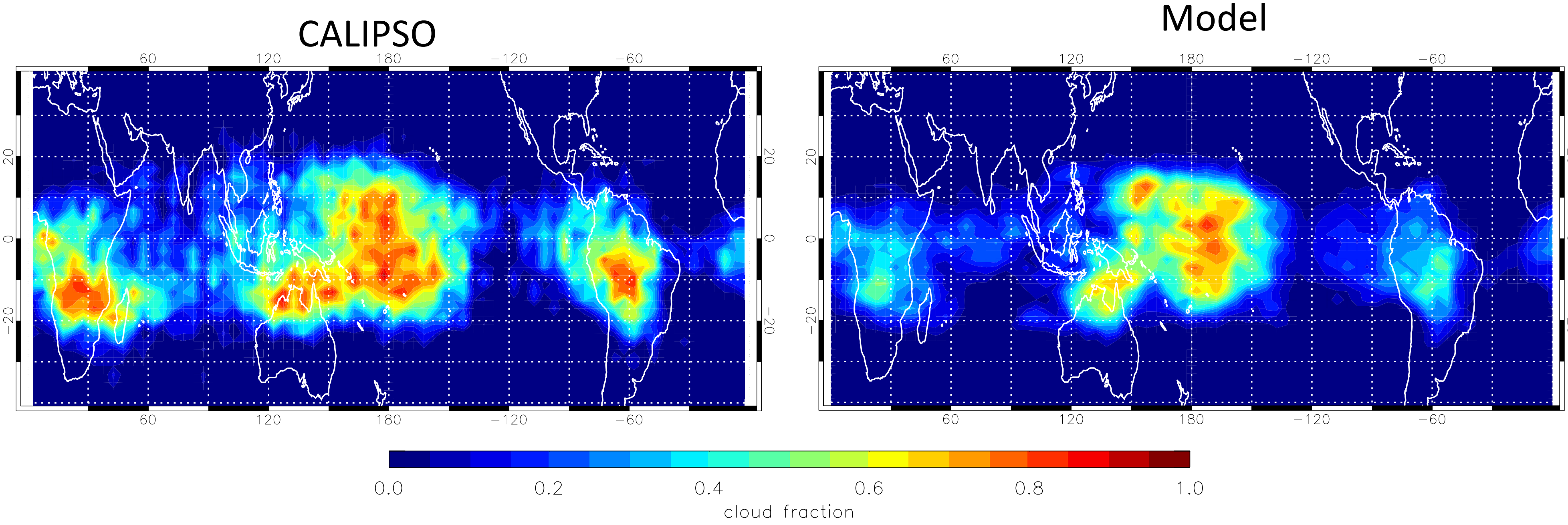
Detrained ice crystals in the TTL (370-400K)





- 40% of convectively-influenced parcels in the tropics at the 378K level during boreal winter are influenced by convection over the western Pacific.
- TTL mean ice saturation ratios exhibit large spatial variability, but near saturation (Si ≈ 1.0) in most convective regions.
- Downstream cooling over W Pacific leads to super-saturated layers above ~375K (not shown).

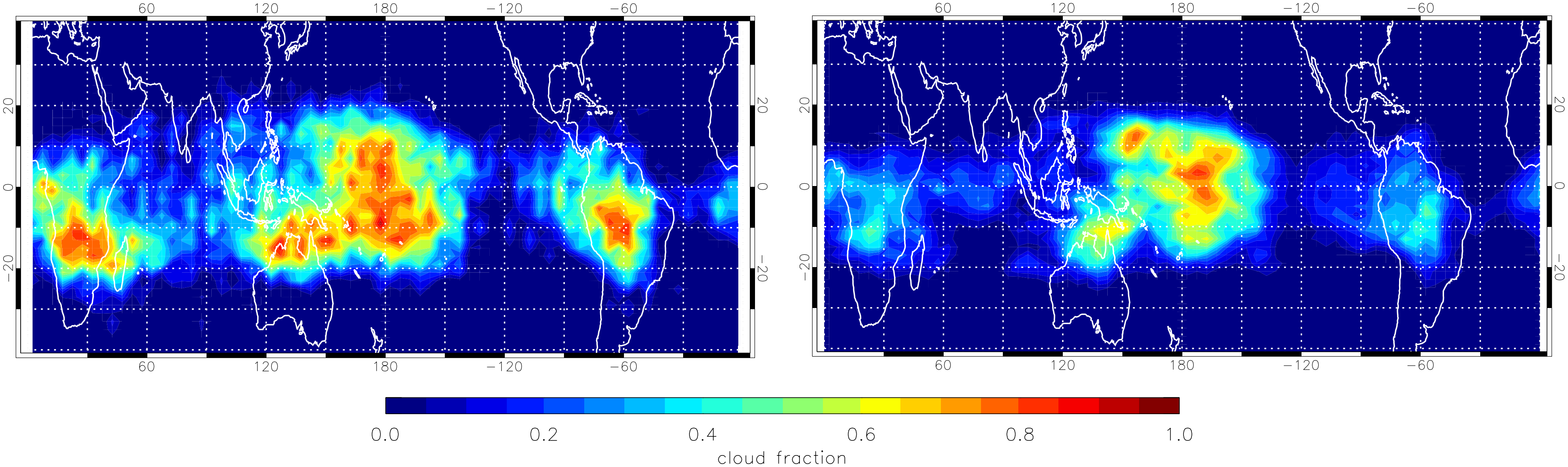
Cloud fraction >16km (Dec 2006 – Feb 2007)



Cloud fraction >16km (Dec 2006 – Feb 2007)

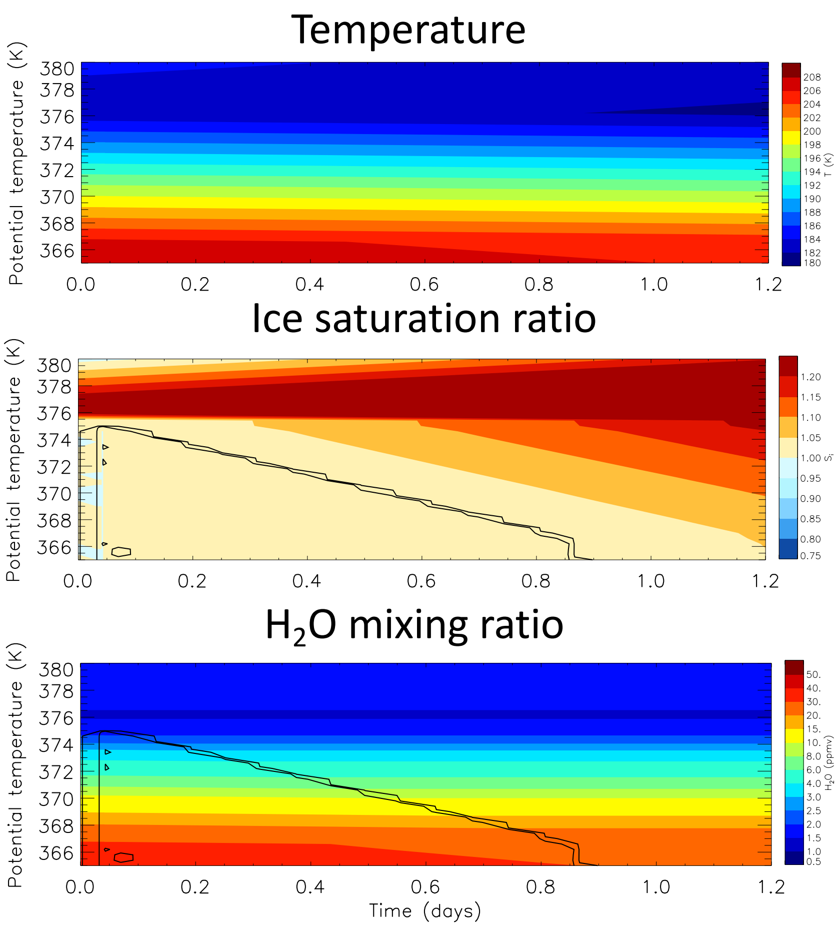
CALIPSO

Model without detrained ice



Detrained ice have very little impact on cloud fraction

Idealized simulations



1) Start with a typical tropical sounding T profile and set relative humidity below 375K to 100%
2) Detrained ice crystals (contours) are injected up to 375K
3) Impose constant heating / cooling at each potential temperature level (i.e., transport of parcels along isentropes that slope upward / downward)

Sensitivity parameters	Percent change in H_2O at 370K
Increase in ice crystal size (R = 15 to 30 µm), monodispersed	+2%
StratoClim ice size distribution (instead of monodispersed, R=15 µm, 100 L^{-1})	–14%
Increase in ice concentration (30 to 300 L^{-1}), StratoClim	+12%
Downstream temperature tendency	6-8% per 1K/d